

Open charm production in high multiplicity proton-proton events at the LHC

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Abstract

We present the dependence of D production on the charged particle multiplicity in proton-proton collisions at LHC energies. We show that, in a framework of source coherence, the open charm production exhibits a growth with the multiplicity which is stronger than linear in the high density domain. This departure from linearity was previously observed in the J/ψ inclusive data from proton-proton collisions at 7 TeV and was successfully described in our approach. Our assumption, the existence of coherence effects present in proton-proton collisions at high energy, applies for high multiplicity proton-proton collisions in the central rapidity region and should affect any hard observable.

1 Introduction

The available data recoiled at RHIC [1, 2, 3, 4] and LHC [5, 6, 7] on heavy-ion collisions have already shown several features which indicate the formation of a high-density partonic medium. In which concerns pp collisions at LHC energies, the energy densities achieved in the high multiplicity events are similar to the ones reached in CuCu central collisions or AuAu peripheral collisions at $\sqrt{s_{NN}} = 200$ GeV. It is then mandatory to look for observables which could reflect the formation of a high density medium, similar to the one already observed in heavy-ion collisions.

One of those signals, already reported by the ALICE collaboration [8, 9], was the rise of central rapidity J/ψ inclusive production in the highest multiplicity events obtained in pp collisions at 7 TeV, that was successfully reproduced in the source interaction framework [10].

Here we address to the production of open charm mesons. We will restrict ourselves to the study of the lightest ones, D^0 , D^+ and D^- , and we will comment on the other states.

2 The model

Let us recall the essential ingredients of our model. Our main assumption consists on considering high-energy hadronic collisions as driven by the exchanged of colour sources –strings– between the projectile and the target. Those sources have finite spatial extension and thus they can interact, reducing their effective number.

Note that one can distinguish between soft and hard sources, depending on their transverse mass, i.e. their quark composition and their transverse momentum. Note also that their transverse size is determined by this transverse mass, since $r_T \propto 1/m_T$. The softness of the source maximizes its possibility of interaction, since its transverse size will be larger.

The main consequence is that the bulk properties –as the total multiplicities– that are driven by the soft sources are going to be affected by their initial interactions, in particular reducing the total number of produced particles in similar way as shadowing or saturation do. On the other hand, the hard events are less affected by source interaction and can be taken as proportional to the number of collisions.

Specifically, in our model each parton-parton collision is reflected as the number of initially produced sources N_s . The hard events in pp collisions are mainly controlled by this number, i.e. the number of collisions. On the contrary, the multiplicity distribution $dN/d\eta$ –mainly soft– is not proportional to the number of collisions, but mostly to the number of participants. This reduction can be considered as a consequence of shadowing in the case of pA or AA collisions [11], parton saturation [12] or, as it is the case here, string interactions [13]. As a consequence, the charged particle multiplicities can suffer a reduction due to the interaction among the sources and behave roughly as $\sqrt{N_s}$. The above assumptions are similar to the fact that the shadowing effects decrease with the hardness of the probe.

In particular, in our approach the multiplicity distribution is given by

$$\frac{dN}{d\eta} = F(\rho)N_s\mu_1 \quad (1)$$

where μ_1 corresponds to the multiplicity of a single source in the rapidity range of interest, N_s is the number of produced sources and $F(\rho)$ corresponds to the damping factor induced by the source interaction,

$$F(\rho) = \sqrt{\frac{1 - e^{-\rho}}{\rho}}. \quad (2)$$

ρ corresponds to the source density, $\rho = \frac{N_s\sigma_0}{\sigma}$, being σ_0 the transverse size of one source and σ the transverse area of the collision.

In our previous paper [10] we have assumed the proportionality between the number of produced J/ψ and the number of collisions,

$$\frac{n_{J/\psi}}{\langle n_{J/\psi} \rangle} = \frac{N_s}{\langle N_s \rangle}, \quad (3)$$

obtaining the relation between the charged particle multiplicity and the number of produced J/ψ ,

$$\frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle} = \left(\frac{n_{J/\psi}}{\langle n_{J/\psi} \rangle} \right)^{1/2} \left[\frac{1 - e^{-\frac{n_{J/\psi}}{\langle n_{J/\psi} \rangle} \langle \rho \rangle}}{1 - e^{-\langle \rho \rangle}} \right]^{1/2} \quad \text{where } \langle \rho \rangle = \langle N_s \rangle \frac{\sigma_0}{\sigma}. \quad (4)$$

The above equation leads to the following behaviour for the J/ψ production: At low multiplicities, where the number of sources $\langle N_s \rangle$ is small, one obtains the linear dependence

$$\frac{n_{J/\psi}}{\langle n_{J/\psi} \rangle} = \frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle}, \quad (5)$$

while, at high multiplicities,

$$\frac{n_{J/\psi}}{\langle n_{J/\psi} \rangle} = \langle \rho \rangle \left(\frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle} \right)^2, \quad (6)$$

where the linear dependence changes to an squared dependence when high multiplicity events are at play. This can be parametrised by the following expression [10]:

$$\frac{n_{J/\psi}}{\langle n_{J/\psi} \rangle} = (1 - \langle \rho \rangle) \left(\frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle} \right) + \langle \rho \rangle \left(\frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle} \right)^2, \quad (7)$$

which agrees extremely well the available experimental data [8, 9].

Let us now face the problem of open charm production. We have considered that, in first approximation, D production is driven both by light and hard sources, due to their mixed composition. Both contributions are to be taken at 50%. The soft contribution will follow the linear behaviour with the multiplicity, while the hard one will behave as the J/ψ does, according to eq. (7),

$$\frac{n_D}{\langle n_D \rangle} = 0.5 \left(\frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle} \right) + 0.5 \left[(1 - \langle \rho \rangle) \left(\frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle} \right) + \langle \rho \rangle \left(\frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle} \right)^2 \right]. \quad (8)$$

Table 1: Relative charged-particle pseudorapidity densities, mean source densities, and relative J/ψ and D yields according to eqs. (7,8).

$\frac{\frac{dN}{d\eta}}{\langle \frac{dN}{d\eta} \rangle}$	$\langle \rho \rangle$	$\frac{n_{J/\psi}}{\langle n_{J/\psi} \rangle}$	$\frac{n_D}{\langle n_D \rangle}$
1	0.09	1.00	1.00
2	0.16	2.32	2.16
3	0.23	4.37	3.69
4	0.29	7.46	5.73
5	0.34	11.88	8.44
6	0.40	17.88	11.94
7	0.46	26.15	16.58
8	0.51	36.73	22.36
9	0.58	50.69	29.84

In order to compare with the available pp experimental data, we need to compute the dependence of the source densities with the multiplicities. In Table 1, we show our values for the available experimental beams together with our results for J/ψ and D production according to eqs. (7,8). Note that the D meson results shown in the above table corresponds to the lightest ones, i.e. D^0 , D^+ , D^- , and are to be taken as p_T integrated, i.e. $p_T > 0$ GeV.

The experimental results on open charm production are presented for different species and different p_T cuts. In order to compare with experimental data [14], we have taken the lowest p_T beam, i.e. $2 < p_T < 4$ GeV for D^0 and D^+ production. In Fig. 1, we show our results compared to experimental ALICE data [14] for D meson production in pp collisions at 7 TeV in the central rapidity range.

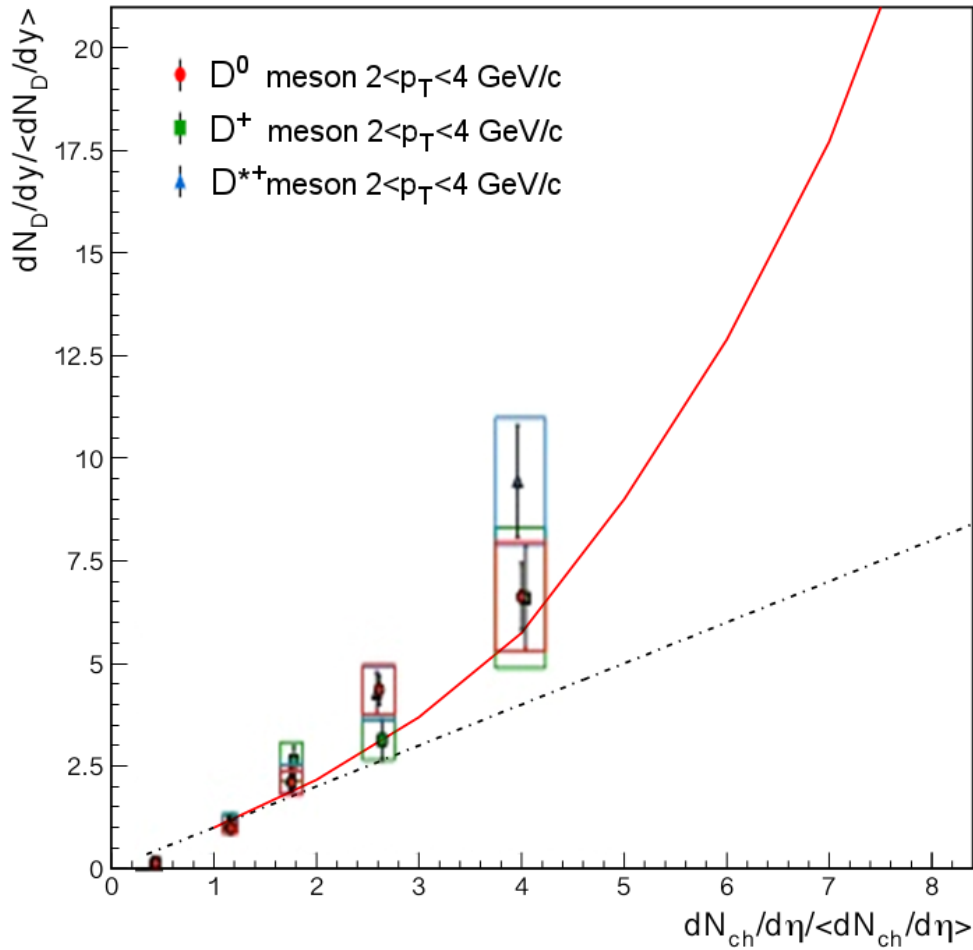


Figure 1: Our results on D meson production (red line) for pp collisions in the central rapidity range, together with the experimental data from the ALICE Collaboration [14]. The linear behaviour (black line) is also plotted.

We observe a good agreement between our result and the experimental data for D^0 and D^+ production. Note that, in which concerns D^* production, its departure from linearity is to be more important, due to its higher mass. Moreover, we can advance that the departure from linearity should also be more important for

the high p_T beams when compare to the low p_T beams.

In Fig. 2, our results on D and J/ψ are plotted and compared to experimental data.

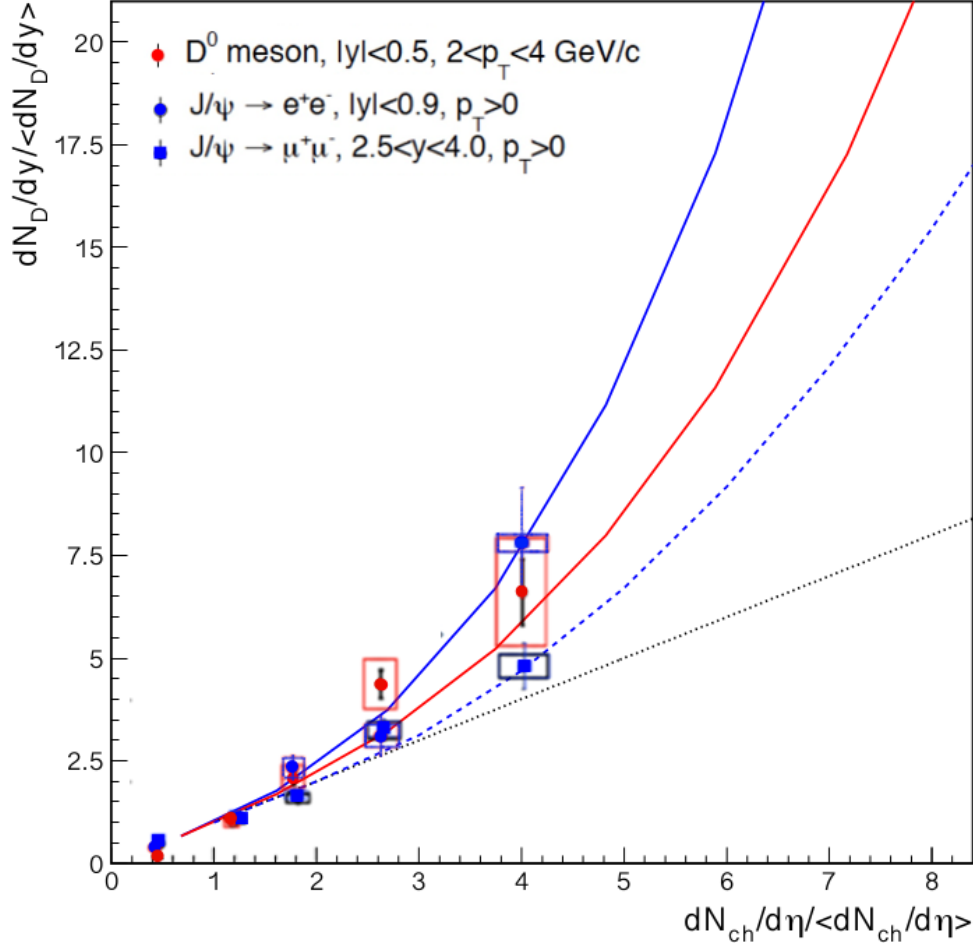


Figure 2: Our results on D meson production in the central rapidity range (red line) and on J/ψ production in the central (continuous blue line) and in the forward (dashed blue line) rapidity range for pp collisions at 7 TeV, together with the experimental data from the ALICE Collaboration [14]. The linear behaviour (black line) is also plotted.

Note that the J/ψ production obeys a quadratic dependence with the multiplicity in the central rapidity region, while it is closer to linear dependence in the forward rapidity one [10].

3 Conclusions

In conclusion, we have reproduced here the rise of D and J/ψ production for the highest multiplicity events at central rapidity observed by the ALICE collaboration in pp collisions. This increase may be a consequence of the formation of a high density medium in pp collisions at LHC energies.

At these high densities, the coherence among the sources can lead to a reduction of their effective number –initially proportional to the number of collisions. This reduction would mainly affect the soft observables, as the total multiplicity, while the hard production would remain unaltered. In this case, the linear dependence of D and J/ψ production on the charged particle multiplicity obtained for low multiplicities –where the parton densities are smaller–, changes to an squared dependence when high multiplicity events are at play. Moreover, this departure from linearity should increase with the hardness of the studied observable. This means that, for the same p_T and rapidity range, the J/ψ production will be higher than the D^0 production for the high multiplicity events. For the same particle specie there should be also an ordering in p_T , i.e. the highest p_T particles should show a most important departure of linearity.

Note that any additional J/ψ suppression –due to the possibility of string or source percolation–, which could lead to a corresponding increase of the D production, cannot be at play at these energies and multiplicities, since the density of strings is well below the threshold for percolation, $\eta > 1$. This threshold can be nevertheless achieved in pp collisions at higher energies, i.e. 14 TeV, for the high multiplicity events, $\frac{dN}{d\eta} > 8$ and also in pPb collisions at 5.02 TeV. In the latest case, the application of our model is not completely straightforward, since other cold nuclear matter effects can be at play here.

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